# Sensitivity of PMED Software Predicted Distresses in New Flexible Pavements for Changes in Granular Materials

Shivpal Yadav, Ph.D., P.Eng.
Pavement and Materials Engineer
Thurber Engineering Ltd.
Pickering, Ontario
syadav@thurber.ca

Julie Roby, M.A.Sc., P.Eng.
Pavement Design Engineer
Ministère des Transports et de la Mobilité durable
Quebec, Quebec
Julie.Roby@transports.gouv.qc.ca

Diana Podborochynski, M.Sc., P.Eng.
Senior Surfacing Standards Engineer
Ministry of Highways
Saskatoon, Saskatchewan
Diana.Podborochynski@gov.sk.ca

M. Alauddin Ahammed, Ph.D., P.Eng.
Manager, Pavement and Materials Engineering Section
Manitoba Transportation and Infrastructure
Winnipeg, Manitoba
Alauddin.Ahammed@gov.mb.ca

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## Abstract

Granular base and subbase layers constitute important layers in flexible pavement structures in Canada. Field experience has demonstrated that high-quality and thicker granular layers enhance pavement performance by increasing load-bearing capacity, improving subsurface drainage, and providing greater resistance to frost and freeze–thaw damage. The AASHTOWare Pavement ME Design (PMED) software has been designed to predict several key distresses in pavements for varied inputs of traffic loads, layer materials, subgrade and climate. However, previous studies have indicated that PMED does not adequately capture the influence of granular base and subbase materials compared to observed field performance. As part of continued design trials since 2007 to assess the suitability of the PMED software, the Transportation Association of Canada (TAC) ME Pavement Design Subcommittee completed a study in 2025 to assess these findings using the latest version of the software. This study included two granular base and two granular subbase materials with different stiffness, gradation, and other physical properties. Two different thickness of each layer material were also employed. Design trials were completed across eleven Canadian climatic regions, while traffic loading, asphalt layers, and subgrade conditions remained unchanged in all these trials.

Results indicate that rutting is more influenced by climatic condition than by variations in granular base and subbase properties, with thickness and stiffness showing negligible effects with some inconsistencies. Thicker and stronger granular base and subbase generally reduce bottom-up fatigue cracking (BUFC). Predicted top-down fatigue cracking (TDFC) exhibits negligible or inconsistent sensitivity to changes in granular base thickness and stiffness property. Similarly, variations in subbase thickness show minimal or inconsistent influence, while its stiffness show no effect on the predicted TDFC. Observed trends indicate that thicker and weaker granular base and subbase result in increased rutting in the respective layer. However, a thicker base reduces rutting in the subbase layer, whereas a weaker base material shows negligible or inconsistent effects on it. Subgrade rutting decreases with increased thickness and stiffness of base/subbase, which is consistent with the expected pavement behaviour. This paper presents the details of these trial results, analyses and implications for evaluating the suitability of PMED in representing the effects of granular base and subbase properties on pavement performance.


## Introduction and Background

Unbound aggregate base and granular subbase are commonly used in flexible pavements. They serve as structural support for distributing wheel loads. Granular pavement layers are designed to drain water, protect the subgrade, and provide frost protection in cold climates. Experience has shown that increasing granular layer thickness and stiffness enhance the performance of flexible pavements due to increased structural capacity and frost protection.

AASHTOWare Pavement ME Design (PMED) predicts total rut depth for asphalt, aggregate base, and subgrade layers, load-related cracking (alligator cracking and longitudinal cracking), thermal cracking, and smoothness. For each performance indicator, PMED has a distress prediction model that requires inputs from different layers in a pavement structure. Required design inputs for granular base and subbase layers include resilient modulus, layer thickness, Poisson's ratio, and the soil water characteristic curve (SWCC).

The TAC ME Pavement Design Subcommittee have studied PMED software predicted distresses related to base and subbase materials and have found that the variation of the predicted IRI is not sensitive to base[1] and subbase[2] thickness and stiffness. The predicted total rutting increases for weaker subbase material

but the effect of thickness is inconsistent. Stiffer and thicker subbase results in increased AC layer rutting using PMED. The granular base layer only has a slight impact on total rutting. Weaker and thinner base and subbase material increased the predicted fatigue cracking, but subbase stiffness had no effect on the top-down fatigue cracking (TDFC) and subbase thickness had a moderate effect on TDFC. The granular base or subbase to subgrade modulus ratios did not have noticeable effect on the predicted distresses for flexible pavements while, climate conditions affect all distresses. It was concluded that overall, PMED software was not yet able to capture the realistic field-observed effect from granular base materials.

Studies in different jurisdictions have shown that the PMED software, which is the latest and most sophisticated pavement design and analysis tool, is unable to adequately consider the effect of the granular base thickness and stiffness as expected based on past performance experience. As part of continued design trials since 2007 to assess the suitability of the PMED software, the TAC ME Pavement Design Subcommittee undertaken this study in 2025 to verify the findings of earlier studies using the latest version of the software. This study included two granular base and two granular subbase materials each having unique stiffness, gradation and other physical properties. Two different thickness of each layer material were also employed. Design trials were completed across eleven Canadian climatic regions, while traffic loading, asphalt layers, and subgrade conditions remained unchanged.

## Findings from Literature Review

The most important concept of a flexible asphalt pavement is the load distribution layered system, with progressively stronger layers near the top. The asphalt concrete surface and the granular underlying pavement layers all work together. The materials and aggregates are intentionally selected with consideration given to material quality and performance, standards and specifications, pavement design method, life cycle costs including maintenance and rehabilitation, and overall road operational performance. Granular base is important because it provides support and strength to the road. The subbase layer is important because it provides frost protection, strength to the road, and supports the base course. The gradation of a base or subbase material is used to determine aggregate particle size distribution, which has a considerable impact on stability, compaction, strength, drainage, and frost susceptibility. Granular pavement layers should be stable when compacted and provide stiffness, strength, resistance to fatigue, frost protection to the subgrade, and permeability in a pavement structures.

There are numerous flexible pavement design methods that have different advantages and limitations. While PMED software predicts total rut depth for asphalt, aggregate base, subbase, and subgrade layers, load-related cracking (alligator cracking and longitudinal cracking), thermal cracking, and smoothness, most pavement design methods do not predict as many distresses.

The AASHTO 1993[3] Pavement Design Guide is an empirical design approach used for designing flexible and rigid pavement. It is based on performance data from the AASHO Road Test that took place in Illinois in the 1960s. AASHTO 1993 uses traffic loads, soil strength, pavement materials, and reliability to determine an abstract structural number for flexible pavements which represent the total structural strength of the pavement structure considering layer thicknesses, layer coefficients, and drainage. The AASHTO 1993 flexible pavement design method has limitations: no mixed traffic is used, and the empirical equations are based on a two-year accelerated testing period from the AASHO Road Test based on the climate, environment, and trucks used. The performance is characterized by the Serviceability index rather than rut depth and it is not possible to know how each pavement layer is contributing to the rutting.

The Saskatchewan Method for flexible pavement design[4] uses Shell Curves developed by Shell research. Shell curves were modified for Saskatchewan conditions and relate asphalt concrete and granular thicknesses to traffic loading. The Shell design method uses linear elastic multi-layer theory to establish design criteria for stresses and strains in a pavement structure, due to an applied wheel load. The Saskatchewan Method uses two critical stresses in a pavement structure in design – the horizontal tensile stress at the bottom of the AC layer which indicates fatigue cracking and the vertical compressive stress at the top of the subgrade which indicates rutting in the subgrade. Using this design method, the goal is to satisfy both tensile strain (fatigue cracking) in the asphalt concrete and compressive stress (rutting) in the subgrade. The Saskatchewan Method assumes that traffic is constant, the subgrade CBR is constant, and the vertical strain in the subgrade and horizontal tensile strain in the AC are also constant. To improve susceptibility to fatigue cracking and rutting, additional granular material (base or subbase) is incorporated into the pavement structure design. Like any pavement design method, the Saskatchewan Method has limitations. It was modified for Saskatchewan materials and rural road design, not applicable to urban design. The only environment input is using the soaked California Bearing Ratio (CBR). The method does not account for subgrade frost susceptibility or clay swell potential. You cannot use geotextiles or modified materials on the modified curves, and you cannot use any unique loading. It only accounts for two pavement failure modes and distresses.

Resilient modulus is one of the main parameters used to characterize unbound aggregate material and is among the most sensitive parameter inputs affecting the predicted pavement performances in PMED[5]. However, this parameter can vary depending on several factors[6,7,8] such as soil properties (e.g., type of aggregate, particle size and geometry, water content, density, compacting method), laboratory test conditions, temperature, number and frequency of load and stress history, and variations within base layer (more variability led to early distresses[9]).

A study of the impact of climate on flexible pavements[10] found that moisture in the pavement structure had a greater impact compared to temperatures. Granular base and subbase layers are less susceptible to the effects of moisture and frost penetration, as well as the impact of groundwater levels. Granular layer moisture content and permeability directly impact strength, freeze-thaw durability, and pumping potential. Proper drainage and moisture control (reduced fines content) in granular layers are essential for maintaining pavement performance. Past studies have identified that thicker and stiffer granular base and subbase layers reduce stresses and strains in pavements layers and improve rutting performance[11,12]. Increasing granular layers thickness helps mitigate frost heave[13] and increasing the base layer thickness also possibly helps reduce the severity of thermal cracking[14].

When evaluating different aggregate quality and thicknesses for base and subbase layer with MnPAVE program (Minnesota DOT mechanistic-empirical flexible design procedure), Xiao et al.[15] found from statistical analysis that the granular subbase material quality makes a significant impact on both fatigue and rutting prediction. However, granular base quality is primarily related to fatigue prediction only. As compared with fatigue performance, rutting performance can benefit much more from an increase in granular subbase thickness.

Previous prediction models incorporated into PMED were known to overestimate the total rutting of new flexible pavement[16,17] and overestimate permanent deformation for unbound aggregate base and subbase layers[18]. Comparison of level 1, 2 and 3 material characterization demonstrated that PMED overpredicts IRI and rutting compared to the field performance of pavement sections from New Mexico Department of Transportation[19]. Level 1 showed the lowest rutting, closer to reality, whereas the

maximum rutting was found at Level 2. The dynamic modulus of AC layer was underpredicted at Levels 2 and 3 resulting in higher rutting and IRI.

PMED has been known to show little to no sensitivity to unbound layers[2,18,20]. The NCHRP Project 1-47 indicates that thickness and especially resilient modulus of base layer are very sensitive for longitudinal cracking and alligator cracking, but properties of base layer are not very sensitive to rutting and IRI. MEPDG design process is dominated by the AC layer and is less sensitive to base layer compared to AASHTO 1993. The PMED model assumes that subbase moisture condition and stress state are independent and that the subbase is an elastic layer[21]; this is the basis for using the resilient modulus to characterize unbound materials. As a result, PMED software is unable to consider adequately the influence of unbound materials in pavement performance prediction.

In 2019, NCHRP 1-53 Report[22] titled, *Proposed Enhancements to Pavement ME Design: Improved Consideration of the Influence of Subgrade and Unbound Layers on Pavement Performance*, proposed enhancements to the Pavement ME Design procedures that better represented the behaviour and influence of unbound granular layers and subgrade layers for flexible and rigid pavement. Following this report, the PMED software asphalt rutting model, subgrade rutting model, top-down cracking model for asphalt, and smoothness calculations were improved. A web-based version of the AASHTOWare Pavement ME software (Version 3.0) was also released in July 2022.

## Scope, Objectives and Significance

The review of available literatures indicates that several studies have conducted assessment of the impacts of granular aggregate base and subbase stiffness, physical properties and layer thickness on pavement design and performance. Some studies have evaluated the impacts of granular base and subbase input parameters on the PMED software predicted distresses in new flexible pavements. A few of these studies focused on the global sensitivity analysis, whereas others have assessed the impact of each individual input parameter of granular aggregate materials on the PMED software predicted distresses. Several studies have also noted that PMED software models related to the granular aggregate base/subbase do not produce adequate influence of these materials in pavement design and performance prediction using the PMED software. As a result, the software is unable to adequately consider the structural values of granular base and subbase thickness, stiffness and other properties, as expected or practically experienced on as-constructed roads/highways.

In 2025, the TAC ME Pavement Design Subcommittee has carried out several coordinated design trials to evaluate the impacts of granular aggregate base and subbase on the PMED software predicted distresses in new flexible pavements. Two different granular base and two different granular subbase materials were used in these design trials. The resilient moduli values of these materials ranged from 110 to 225 MPa. Two different thicknesses of each material type were employed. The design trials also included varying climate data from 11 different areas of Canada resulting in a total of 88 design runs. The results of these trials allowed for assessing the impact of granular base and subbase material properties including stiffness, layer thickness and climatic exposures on the PMED software predicted distresses. The presented information may help different agencies and other interested individuals in assessing the suitability of the latest web version of the PMED software when designing flexible pavement structures with varied inputs of granular aggregate base and subbase materials.

## Software Versions and General Design Inputs

This study utilized the PMED software version 3.0 using the global calibration coefficients in all design trials. The general input parameters for the design trials are summarized in Table 1, which remained unchanged in all design runs. The varying design inputs for different trial runs included mechanical as well as physical properties and thickness of different granular base and subbase materials and varying climatic data from across Canada. Details of climatic data are presented in the next section. Details of varying input parameters of granular base and subbase layers are presented in "Trial Matrix and Varying Design Inputs" section.

Table 1. General inputs for design trials

| Inputs | | Value Used |
|---|---|---|
| Climate Data | | MERRA-2 from 11 weather stations across Canada |
| Truck Traffic | | Two-way 2,500 trucks/day (1,000 trucks/day on the design lane of a four-lane divided highway) and 2% cumulative annual growth rate |
| Vehicle Class Distribution and Axle Load Spectra | | Manitoba Level 1 |
| Traffic Speed | | 100 km/h |
| Design Life | | 20 years |
| Initial IRI | | 0.9 m/km |
| Design Reliability | | 90 % for all distress types |
| HMA Properties | | **Manitoba SP12.5 mix**: Asphalt binder = 4.8 %; density = 2,276 kg/m$^3$; VMA = 17.2 %; AV = 6.9 %; particles < 9.50 mm = 80.6 %, 4.75 mm = 52.6 % and 0.075 mm = 2.8 %<br>**Manitoba SP19.0 mix**: Asphalt binder = 4.5 %; density = 2,294 kg/m$^3$; VMA = 16.6 %; AV = 7.0 %; particles < 19.0 mm = 95.3 %, 9.50 mm = 67.9 %, 4.75 mm = 51.8 % and 0.075 mm = 3.0 %<br><br>Asphalt binder grade: PG 58-34 in both mixes<br><br>Software default Poisons ratio, reference temperature, thermal conductivity and heat capacity for both mixes |
| Pavement Structures | Asphalt Concrete | Surface layer = 40 mm thick Manitoba SP12.5<br>Base layer = 110 mm thick Manitoba SP19.0 |
| | Granular Base | Varied for the evaluation of the impact of granular base, but remained fixed for the evaluation of the impact of granular subbase |
| | Granular Subbase | Varied for the evaluation of the impact of granular subbase, but remained fixed for the evaluation of the impact of granular base |
| Subgrade Type and Properties | | Soil Type: High Plastic Clay (AASHTO A-7-6); Resilient Modulus = 35 MPa (software default minimum), particles < 9.5 mm = 100 %, 4.75 mm = 99 %, 2.00 mm = 98 %, 0.425 mm = 97 %, 0.075 mm = 92 % and 0.020 mm = 83 %; LL = 79 %; PI = 49 %; density = 1,410 kg/m$^3$; and MC = 29%. |

*IRI = International Roughness Index; SP = SuperPave; VMA = Voids in Mineral Aggregates; AV = Air Voids; PG = Performance Grade; LL = Liquid Limit; PI = Plasticity Index; MC = Moisture Content.*

A 300 mm thick layer of 100 % crushed rock minus 50 mm (Manitoba CR- M50) was used as the subbase in four design trials for each climate station to evaluate the impact of granular base. Other physical

properties of CR- M50 including the gradation and plasticity (particles < 37.5 mm = 100 %, 19 mm = 75 %, 9.5 mm = 55 %, 4.75 mm = 40 %, 2.00 mm = 30 %, 0.075 mm = 8.0 %; non-plastic fines) also remained unchanged in these trials. The CR- M50 had a fixed annual representative resilient modulus (Mr) value of 200 MPa.

A 150 mm thick layer of Manitoba GBC- I, produced from pit run aggregates (60 % particles with fractured faces), was used as the base in four design trials for each weather station to assess the impact of subbase materials. Other physical properties of GBC- I, including gradation and plasticity (particles < 25 mm = 100 %, 19 mm = 95 %, 9.5 mm = 75 %, 4.75 mm = 60 %, 2.00 mm = 45 %, 0.85 mm = 30 %, 0.425 mm = 21 %, 0.18 mm = 14 % and 0.075 mm = 8.0 %; LL = 25% and PI = 3%), remained unchanged. The GBC- I had a fixed annual representative Mr value of 225 MPa.

## Selected Weather Stations and Summary of Climate Data

MERRA-2 climate data from 11 weather stations across Canada with varying climatic input parameters were selected for the design trials presented in this study. Figure 1 shows the geographic locations of selected the weather stations. The red dots indicate relatively warmer climates, while the blue dots indicate relatively colder climates in Canadian context. Table 2 presents the list of weather stations and the summary of the key climatic parameters. It should be noted here that some of the climatic parameters (such as minimum air temperature, frost depths and annual number of wet days) in the MERRA-2 climate database seem to be unreasonable as they do not match actual ground observations.

Figure 1. Geographic locations of weather stations across Canada

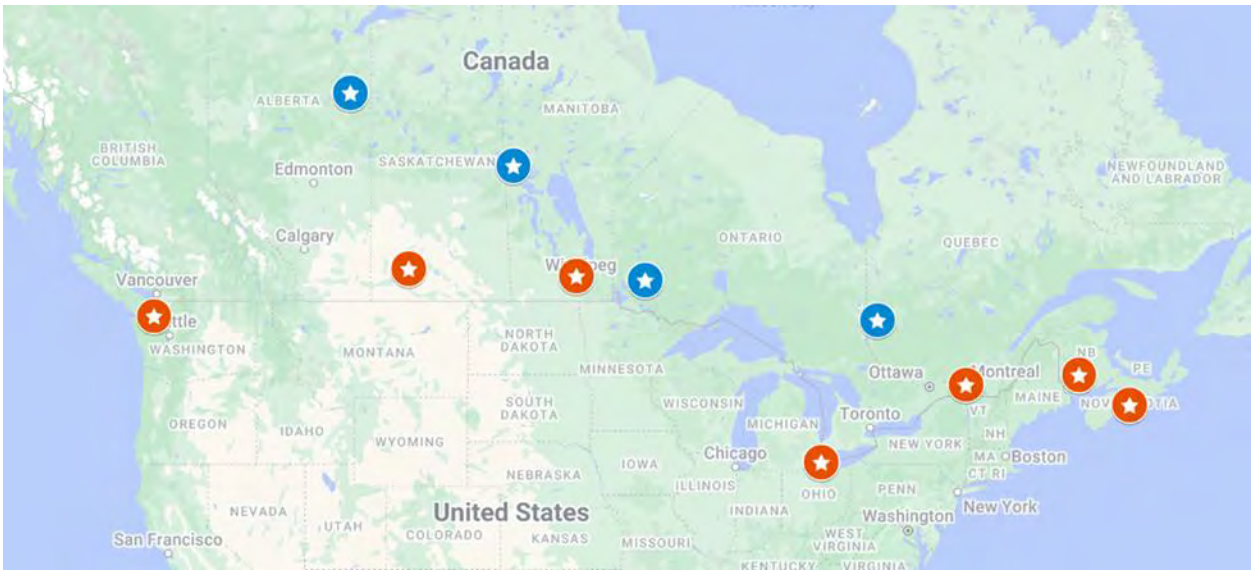


Table 2. List of weather stations and summary of key climatic parameters over the design life

| Weather Station | Annual Air Temp. (°C) | | | Mean Annual | | | |
|---|---|---|---|---|---|---|---|
| | Min. | Max. | Mean | Precipitation (mm) | Number of Wet Days | FI (°C-days) (FD, m) | # of F-T Cycles |
| Victoria, BC | -15.4 | 29.4 | 10.9 | 1502 | 332 | 11 (0.5) | 7.2 |
| Fort McMurray, AB | -47.1 | 36.9 | 0.2 | 630 | 337 | 2081 (4.4) | 66.5 |
| Swift Current, SK | -42.1 | 37.9 | 4.9 | 451 | 274 | 999 (2.0) | 108.6 |
| Winnipeg, MB | -45.9 | 38.3 | 3.5 | 605 | 302 | 1754 (3.2) | 67.6 |
| The Pas, MB | -48.1 | 37.9 | 0.5 | 590 | 329 | 2357 (7.5) | 58.9 |
| Wheatley, ON | -21.7 | 31.6 | 9.6 | 1092 | 304 | 301 (2.0) | 52.0 |
| Waldhof, ON | -48.9 | 33.6 | 1.3 | 858 | 335 | 2131 (4.1) | 56.8 |
| Rouyn, QC | -45.7 | 31.1 | 2.0 | 1226 | 350 | 1794 (2.7) | 67.3 |
| Montreal, QC | -41.5 | 36.7 | 6.2 | 1379 | 326 | 1100 (2.2) | 70.8 |
| Fredericton, NB | -36.2 | 31.8 | 5.0 | 1389 | 345 | 1028 (1.6) | 81.2 |
| Halifax, NS | -20.1 | 27.1 | 7.3 | 1647 | 340 | 315 (1.1) | 70.0 |

*FI = Freezing Index, FD = Frost Depth; F-T = Freeze-Thaw*

## Trial Matrix and Varying Design Inputs

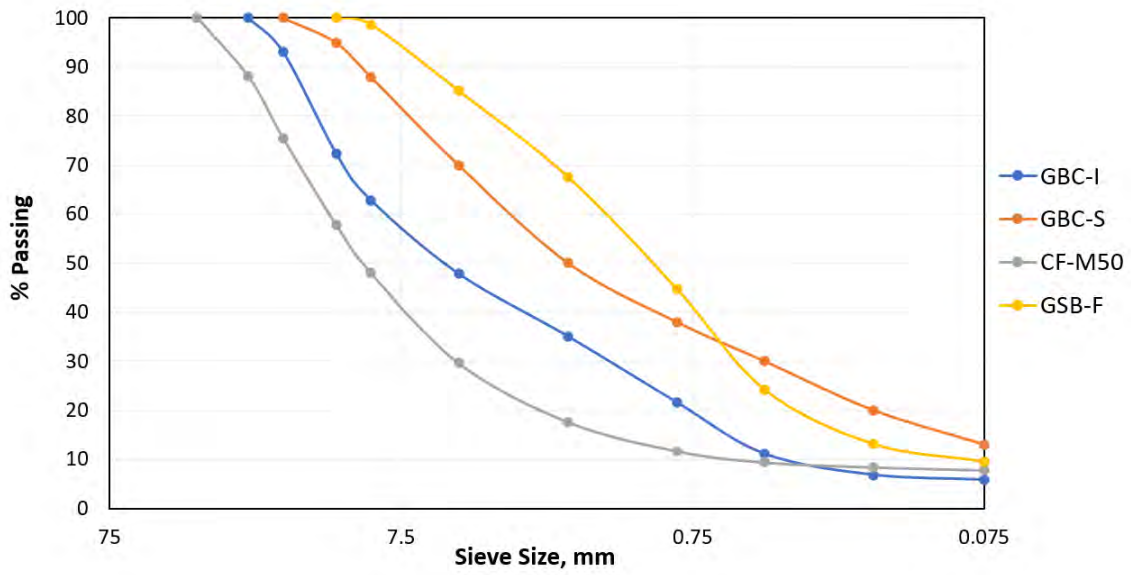
The granular aggregate layer material stiffness, physical properties and the layer thickness have significant contributions to flexible pavement thickness design and performance over the design life and full life cycle. To evaluate the impacts of granular base material properties including stiffness, this study used two different granular aggregate base materials: 1) Manitoba GBC- I, which is a premium quality 100 % crushed limestone granular base course material (PI = 0) with an excellent balance of stability, stiffness and drainage properties; and 2) Manitoba GBC- S, which is a fair quality granular base course material, produced from pit run aggregates (particles with fractured faces = 35 %, LL = 25 % and PI = 6 %), with moderate stiffness and lower drainage quality than GBC- I for use as a granular surface course.

Alternatively, to evaluate the impacts of granular subbase material physical properties and stiffness, two different granular aggregate subbase materials were also used. They include: 1) Manitoba CR- M50, which is a premium quality 100 % crushed limestone granular subbase course material with an excellent balance of stability, stiffness and drainage properties; and 2) Manitoba GSB- F, which is a fair quality granular subbase material, produced from pit run aggregates (LL = 14 % and PI = 0 %), with moderate stiffness and fair drainage quality for use as a select granular fill and/or embankment and/or subbase layer material directly below the GBC layer.

Figure 2 shows the gradations of granular base and subbase materials for which varying inputs were used. The Mr values of these selected base and subbase materials were varied seasonally by the PMED software climate module. Two different thickness of each base and subbase material was employed in these trials to evaluate the impact of layer thickness of each material type. These resulted in a total eight design trials for each weather station and a total of 88 trial runs for 11 weather stations. Table 3 presents the design

trial matrix for each weather station together with data of key input parameters that were used to assess the impacts granular material properties and thickness. The suitability of the PMED software in predicting pavement surface distresses as practically expected or experienced was also assessed through the analysis of the trends of predicted distresses.

Figure 2. Gradation of selected granular base and subbase materials




*GBC- I = Granular Base Course Type I, GBC- S = Granular Base Course Type S (Surface); CR- M50 = Crushed Rock Minus 50 mm, and GSB- F = Granular Subbase Type F (Fill)*

Table 3. Design trial matrix for each weather station

| Trial No. | Granular Base | | | | | Granular Subbase | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Type | Thickness, mm | Mr, MPa | Density, kg/m³ | MC, % | Type | Thickness, mm | Mr, MPa | Density, kg/m³ | MC, % |
| ***Evaluation of the impacts of granular base course materials*** | | | | | | | | | | |
| 1 | GBC-I | **150** | **200** | **2,240** | **7.2** | CR-M50 | 300 | *200 | 2,200 | 8.0 |
| 2 | | **300** | **200** | **2,240** | **7.2** | | 300 | *200 | 2,200 | 8.0 |
| 3 | GBC-S | **150** | **130** | **2,260** | **8.0** | | 300 | *200 | 2,200 | 8.0 |
| 4 | | **300** | **130** | **2,260** | **8.0** | | 300 | *200 | 2,200 | 8.0 |
| ***Evaluation of the impacts of granular subbase course materials*** | | | | | | | | | | |
| 5 | GBC-I | 150 | *225 | 2,230 | 6.9 | CR-M50 | **300** | **220** | **2,065** | **6.8** |
| 6 | | 150 | *225 | 2,230 | 6.9 | | **600** | **220** | **2,065** | **6.8** |
| 7 | | 150 | *225 | 2,230 | 6.9 | GSB-F | **300** | **110** | **2,117** | **7.0** |
| 8 | | 150 | *225 | 2,230 | 6.9 | | **600** | **110** | **2,117** | **7.0** |

*MC = Moisture Content; *Annual representative values; Values in red font indicate varying input parameters*

## Results, Analysis and Discussion

Tables 4a and 4b summarize the results of the design trials completed in this study. The following sections present graphical analyses of predicted pavement distresses to illustrate trends and assess the effects of variations in granular base and subbase materials on pavement performance.

Table 4a. Summary of predicted distresses: BC, AB, SK, MB-Winnipeg, MB- The Pas and ON-Wheatly

| Project Location | Design No. | Predicted Distress at 90% Reliability | | | | | | Predicted Distress at 50% Reliability | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | IRI (m/km) | HMA Rutting (mm) | Total Rutting (mm) | BUFC (%) | TC (%) | TDFC (%) | HMA Rutting (mm) | Base Rutting (mm) | Subbase Rutting (mm) | Subgrade Rutting (mm) |
| Victoria, BC | 1 | 2.27 | 5.71 | 11.89 | 19.90 | 40.97 | 5.88 | 3.93 | 0.89 | 0.99 | 3.57 |
| | 2 | 2.26 | 5.93 | 11.89 | 15.96 | 40.97 | 6.20 | 4.09 | 1.48 | 0.73 | 3.07 |
| | 3 | 2.35 | 5.59 | 12.22 | 31.36 | 40.97 | 5.52 | 3.84 | 1.16 | 0.96 | 3.67 |
| | 4 | 2.35 | 5.73 | 12.44 | 30.63 | 40.97 | 5.52 | 3.95 | 2.00 | 0.73 | 3.21 |
| | 5 | 2.25 | 5.77 | 11.72 | 14.50 | 40.97 | 6.20 | 3.97 | 0.82 | 0.92 | 3.51 |
| | 6 | 2.23 | 6.00 | 11.43 | 8.51 | 40.97 | 7.29 | 4.15 | 0.80 | 1.34 | 2.61 |
| | 7 | 2.3 | 5.57 | 12.34 | 23.07 | 40.97 | 6.20 | 3.83 | 0.83 | 1.38 | 3.76 |
| | 8 | 2.29 | 5.71 | 12.40 | 20.01 | 40.97 | 7.29 | 3.93 | 0.83 | 2.14 | 2.96 |
| Fort McMurray, AB | 1 | 2.66 | 13.93 | 20.30 | 33.41 | 40.98 | 17.15 | 10.16 | 1.10 | 1.14 | 3.71 |
| | 2 | 2.62 | 13.57 | 19.73 | 29.48 | 40.97 | 16.91 | 9.88 | 1.78 | 0.80 | 3.17 |
| | 3 | 2.94 | 13.73 | 20.68 | 68.01 | 40.98 | 17.35 | 10.00 | 1.52 | 1.14 | 3.81 |
| | 4 | 2.96 | 13.98 | 21.08 | 68.91 | 40.98 | 17.15 | 10.20 | 2.49 | 0.82 | 3.32 |
| | 5 | 2.6 | 14.08 | 20.19 | 26.57 | 40.98 | 16.98 | 10.27 | 1.00 | 1.05 | 3.66 |
| | 6 | 2.59 | 14.56 | 20.17 | 23.39 | 40.98 | 16.11 | 10.64 | 1.02 | 1.55 | 2.70 |
| | 7 | 2.69 | 13.65 | 20.67 | 36.45 | 40.98 | 16.98 | 9.94 | 1.01 | 1.61 | 3.92 |
| | 8 | 2.67 | 13.95 | 20.91 | 32.59 | 40.98 | 16.11 | 10.17 | 1.01 | 2.45 | 3.05 |
| Swift Current, SK | 1 | 2.32 | 4.36 | 10.53 | 13.35 | 41.46 | 17.05 | 2.94 | 0.85 | 0.96 | 3.52 |
| | 2 | 2.32 | 4.53 | 10.47 | 9.03 | 41.54 | 16.89 | 3.06 | 1.42 | 0.71 | 3.03 |
| | 3 | 2.33 | 4.28 | 10.87 | 24.94 | 41.43 | 17.23 | 2.88 | 1.15 | 0.95 | 3.61 |
| | 4 | 2.34 | 4.39 | 11.05 | 24.50 | 41.53 | 17.23 | 2.96 | 1.91 | 0.71 | 3.17 |
| | 5 | 2.32 | 4.41 | 10.35 | 7.88 | 41.47 | 16.89 | 2.98 | 0.78 | 0.89 | 3.47 |
| | 6 | 2.3 | 4.68 | 10.10 | 4.28 | 41.64 | 16.21 | 3.18 | 0.80 | 1.34 | 2.59 |
| | 7 | 2.33 | 4.26 | 10.99 | 17.75 | 41.43 | 16.89 | 2.87 | 0.79 | 1.33 | 3.71 |
| | 8 | 2.33 | 4.37 | 11.03 | 13.55 | 41.45 | 16.23 | 2.95 | 0.79 | 2.07 | 2.93 |
| Winnipeg (Rosser), MB | 1 | 2.37 | 5.02 | 11.23 | 18.45 | 47.24 | 17.02 | 3.42 | 0.88 | 0.99 | 3.55 |
| | 2 | 2.37 | 5.20 | 11.19 | 14.50 | 48.07 | 16.86 | 3.56 | 1.47 | 0.73 | 3.05 |
| | 3 | 2.41 | 4.93 | 11.58 | 29.80 | 47.05 | 17.20 | 3.36 | 1.19 | 0.98 | 3.64 |
| | 4 | 2.42 | 5.04 | 11.78 | 29.48 | 47.96 | 17.20 | 3.44 | 1.98 | 0.73 | 3.19 |
| | 5 | 2.37 | 5.08 | 11.06 | 12.68 | 47.41 | 16.86 | 3.47 | 0.81 | 0.92 | 3.50 |
| | 6 | 2.35 | 5.29 | 10.75 | 7.09 | 47.47 | 16.21 | 3.62 | 0.83 | 1.37 | 2.60 |
| | 7 | 2.39 | 4.90 | 11.69 | 21.84 | 46.94 | 16.86 | 3.34 | 0.82 | 1.38 | 3.75 |
| | 8 | 2.38 | 5.03 | 11.75 | 18.60 | 47.00 | 16.21 | 3.43 | 0.82 | 2.13 | 2.95 |
| The Pas (Wanless), MB | 1 | 2.39 | 5.54 | 11.76 | 20.15 | 41.01 | 17.17 | 3.80 | 0.91 | 1.01 | 3.57 |
| | 2 | 2.39 | 5.75 | 11.75 | 16.62 | 41.02 | 16.99 | 3.96 | 1.51 | 0.74 | 3.06 |
| | 3 | 2.45 | 5.44 | 12.13 | 32.49 | 41.01 | 17.36 | 3.73 | 1.24 | 1.00 | 3.66 |
| | 4 | 2.46 | 5.57 | 12.36 | 32.28 | 41.02 | 17.36 | 3.83 | 2.05 | 0.74 | 3.20 |
| | 5 | 2.38 | 5.61 | 11.60 | 14.60 | 41.02 | 16.99 | 3.85 | 0.84 | 0.93 | 3.51 |
| | 6 | 2.37 | 5.83 | 11.31 | 8.72 | 41.02 | 16.30 | 4.02 | 0.85 | 1.39 | 2.61 |
| | 7 | 2.4 | 5.40 | 12.23 | 23.21 | 41.01 | 16.99 | 3.70 | 0.85 | 1.41 | 3.76 |
| | 8 | 2.4 | 5.55 | 12.30 | 20.27 | 41.01 | 16.30 | 3.81 | 0.84 | 2.17 | 2.95 |
| Wheatley, ON | 1 | 2.33 | 4.93 | 11.12 | 18.21 | 40.97 | 14.78 | 3.36 | 0.87 | 0.98 | 3.56 |
| | 2 | 2.33 | 5.10 | 11.07 | 14.20 | 40.97 | 14.80 | 3.49 | 1.44 | 0.72 | 3.06 |
| | 3 | 2.38 | 4.84 | 11.47 | 29.06 | 40.97 | 14.70 | 3.29 | 1.17 | 0.97 | 3.65 |
| | 4 | 2.38 | 4.97 | 11.66 | 28.74 | 40.97 | 14.70 | 3.38 | 1.94 | 0.73 | 3.20 |
| | 5 | 2.33 | 4.98 | 10.95 | 12.48 | 40.97 | 14.80 | 3.40 | 0.80 | 0.91 | 3.50 |
| | 6 | 2.32 | 5.18 | 10.62 | 6.90 | 40.97 | 14.67 | 3.54 | 0.81 | 1.36 | 2.60 |
| | 7 | 2.35 | 4.82 | 11.59 | 21.72 | 40.97 | 14.80 | 3.27 | 0.81 | 1.36 | 3.75 |
| | 8 | 2.35 | 4.94 | 11.63 | 18.37 | 40.97 | 14.67 | 3.36 | 0.80 | 2.11 | 2.95 |

*IRI = International roughness index, BUFC = bottom-up fatigue cracking, TC = transverse cracking, TDFC = top-down fatigue cracking*

Table 4b. Summary of predicted distresses: ON-Waldhof, Rouyn-QC, Montreal-QC, NB and NS

| Project Location | Design No. | Predicted Distress at 90% Reliability | | | | | | Predicted Distress at 50% Reliability | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | IRI (m/km) | HMA Rutting (mm) | Total Rutting (mm) | BUFC (%) | TC (%) | TDFC (%) | HMA Rutting (mm) | Base Rutting (mm) | Subbase Rutting (mm) | Subgrade Rutting (mm) |
| Waldhof, ON | 1 | 2.46 | 7.58 | 13.83 | 24.13 | 41.03 | 17.11 | 5.39 | 0.90 | 1.00 | 2.62 |
| | 2 | 2.46 | 7.82 | 13.85 | 21.32 | 41.06 | 16.95 | 5.50 | 1.60 | 0.76 | 3.09 |
| | 3 | 2.59 | 7.40 | 14.14 | 40.98 | 41.03 | 17.32 | 5.18 | 1.33 | 1.04 | 3.70 |
| | 4 | 2.59 | 7.57 | 14.43 | 41.18 | 41.05 | 17.32 | 5.31 | 2.19 | 0.77 | 3.23 |
| | 5 | 2.45 | 7.64 | 13.64 | 19.25 | 41.03 | 16.95 | 5.37 | 0.89 | 0.97 | 3.54 |
| | 6 | 2.44 | 7.94 | 13.43 | 14.09 | 41.03 | 16.27 | 5.59 | 0.90 | 1.44 | 2.63 |
| | 7 | 2.48 | 7.37 | 14.22 | 26.77 | 41.02 | 16.95 | 5.16 | 0.90 | 1.47 | 3.80 |
| | 8 | 2.47 | 7.55 | 14.34 | 24.00 | 41.03 | 16.27 | 5.30 | 0.89 | 2.25 | 2.98 |
| Rouyn, QC | 1 | 2.75 | 15.82 | 22.20 | 34.32 | 40.99 | 17.10 | 11.62 | 1.12 | 1.15 | 3.72 |
| | 2 | 2.73 | 16.27 | 22.45 | 30.84 | 40.99 | 16.77 | 11.97 | 1.82 | 0.81 | 3.18 |
| | 3 | 3.04 | 15.57 | 22.53 | 71.01 | 40.98 | 17.29 | 11.42 | 1.56 | 1.16 | 3.82 |
| | 4 | 3.06 | 15.83 | 22.95 | 71.71 | 40.99 | 17.10 | 11.63 | 2.54 | 0.83 | 3.32 |
| | 5 | 2.69 | 15.99 | 22.09 | 27.03 | 40.98 | 16.93 | 11.75 | 1.02 | 1.06 | 3.66 |
| | 6 | 2.67 | 16.52 | 22.13 | 23.90 | 40.99 | 16.08 | 12.16 | 1.03 | 1.56 | 2.70 |
| | 7 | 2.78 | 15.48 | 22.50 | 37.06 | 40.98 | 16.93 | 11.35 | 1.03 | 1.63 | 3.93 |
| | 8 | 2.76 | 15.81 | 22.78 | 33.31 | 40.98 | 16.08 | 11.61 | 1.03 | 2.47 | 3.05 |
| Montreal, QC | 1 | 2.4 | 4.78 | 11.00 | 18.76 | 54.89 | 16.55 | 3.25 | 0.87 | 0.98 | 3.56 |
| | 2 | 2.4 | 4.95 | 10.94 | 14.81 | 57.85 | 16.44 | 3.37 | 1.40 | 0.71 | 3.06 |
| | 3 | 2.44 | 4.69 | 11.34 | 29.90 | 54.23 | 16.67 | 3.18 | 1.17 | 0.98 | 3.65 |
| | 4 | 2.44 | 4.80 | 11.52 | 29.48 | 57.52 | 16.67 | 3.26 | 1.95 | 0.73 | 3.20 |
| | 5 | 2.39 | 4.83 | 10.82 | 13.11 | 55.36 | 16.44 | 3.29 | 0.80 | 0.91 | 3.50 |
| | 6 | 2.38 | 5.03 | 10.50 | 7.38 | 55.60 | 15.98 | 3.43 | 0.82 | 1.37 | 2.61 |
| | 7 | 2.41 | 4.66 | 11.48 | 22.15 | 54.23 | 16.44 | 3.16 | 0.79 | 1.34 | 3.75 |
| | 8 | 2.41 | 4.79 | 11.52 | 18.91 | 54.20 | 15.98 | 3.25 | 0.81 | 2.12 | 2.95 |
| Fredericton, NB | 1 | 2.76 | 15.40 | 21.80 | 37.46 | 40.97 | 16.74 | 11.29 | 1.11 | 1.15 | 3.74 |
| | 2 | 2.75 | 16.43 | 22.63 | 34.12 | 40.97 | 16.48 | 12.09 | 1.82 | 0.82 | 3.20 |
| | 3 | 3.08 | 15.52 | 22.51 | 76.71 | 40.97 | 16.98 | 11.38 | 1.55 | 1.16 | 3.85 |
| | 4 | 3.1 | 15.92 | 23.07 | 77.71 | 40.97 | 16.79 | 11.70 | 2.54 | 0.83 | 3.34 |
| | 5 | 2.71 | 16.34 | 22.48 | 29.80 | 40.97 | 16.45 | 12.02 | 1.02 | 1.06 | 3.69 |
| | 6 | 2.68 | 16.71 | 22.35 | 26.24 | 40.97 | 15.79 | 12.31 | 1.04 | 1.57 | 2.72 |
| | 7 | 2.81 | 15.57 | 22.62 | 41.48 | 40.97 | 16.64 | 11.42 | 1.03 | 1.63 | 3.96 |
| | 8 | 2.78 | 15.86 | 22.86 | 36.95 | 40.97 | 15.80 | 11.65 | 1.03 | 2.48 | 3.07 |
| Halifax (Terence Bay), NS | 1 | 2.34 | 3.79 | 9.97 | 13.56 | 40.97 | 15.55 | 1.19 | 0.68 | 0.86 | 3.12 |
| | 2 | 2.33 | 3.98 | 9.93 | 9.47 | 40.97 | 15.45 | 1.89 | 1.38 | 0.71 | 3.04 |
| | 3 | 2.35 | 3.75 | 10.35 | 24.85 | 40.97 | 15.48 | 2.65 | 1.24 | 1.00 | 3.66 |
| | 4 | 2.35 | 3.85 | 10.51 | 24.40 | 40.97 | 15.48 | 1.90 | 1.85 | 0.71 | 3.18 |
| | 5 | 2.33 | 3.87 | 9.84 | 8.50 | 40.97 | 15.48 | 1.83 | 0.76 | 0.88 | 3.47 |
| | 6 | 2.32 | 4.04 | 9.48 | 4.34 | 40.97 | 15.22 | 1.87 | 0.77 | 1.32 | 2.59 |
| | 7 | 2.35 | 3.73 | 10.49 | 18.37 | 40.97 | 15.48 | 1.83 | 0.77 | 1.31 | 3.72 |
| | 8 | 2.34 | 3.07 | 9.71 | 9.04 | 40.97 | 15.70 | 1.48 | 0.73 | 1.98 | 2.92 |

*IRI = International roughness index, BUFC = bottom-up fatigue cracking, TC = transverse cracking, TDFC = top-down fatigue cracking*

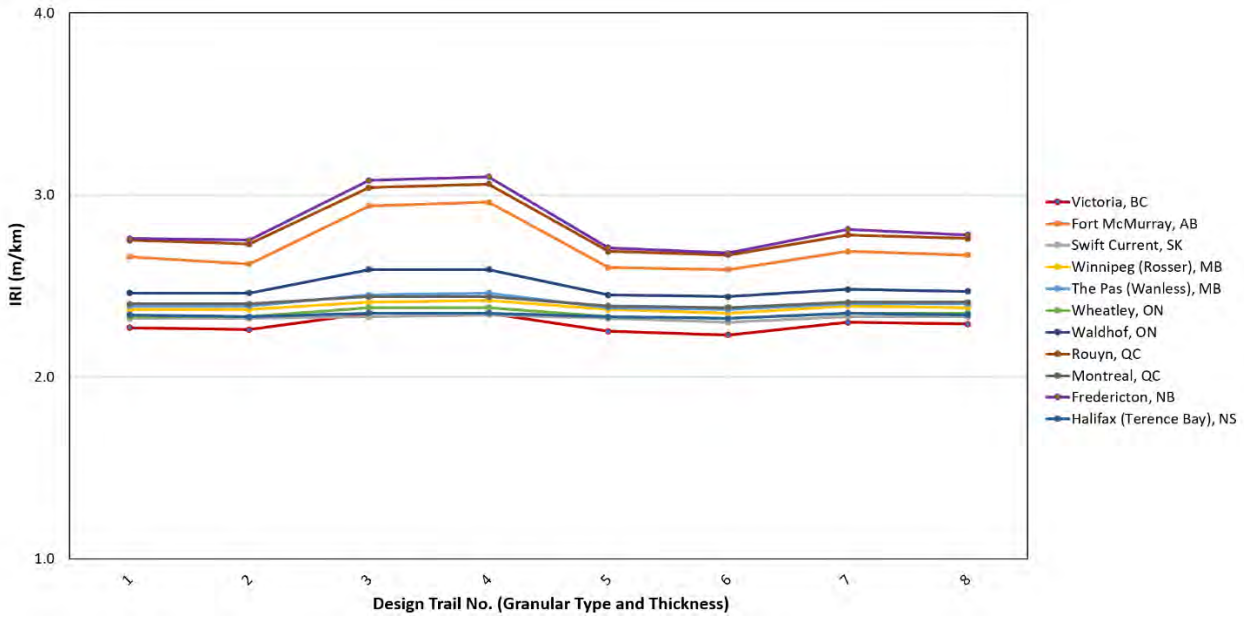
## Effects of Changes in Granular Base and Subbase Materials

The effects of variations in granular base and subbase materials, including changes in material type and layer thickness, on the PMED software predicted distresses were evaluated using the design trial matrix described earlier. The trends of predicted distresses were examined across different climatic regions to assess both the sensitivity and consistency of PMED predictions and are presented in Figures 3 to 10 below.

### *Impact of Granular Materials on Predicted IRI*

The trends of the PMED software predicted IRI for variations in granular base and subbase material types and thicknesses are presented in Figure 3. The results indicate that the predicted IRI shows minimal sensitivity to changes in granular material properties, typically varying by less than 0.1 to 0.2 m/km between different granular type and thickness combinations. In contrast, climate has a strong influence on IRI. Colder regions (e.g., Fort McMurray, Rouyn, Fredericton) exhibit higher IRI values, while milder climates (e.g., Victoria, Wheatley, Halifax) show lower IRI values.

Figure 3. Effects of granular materials on predicted IRI

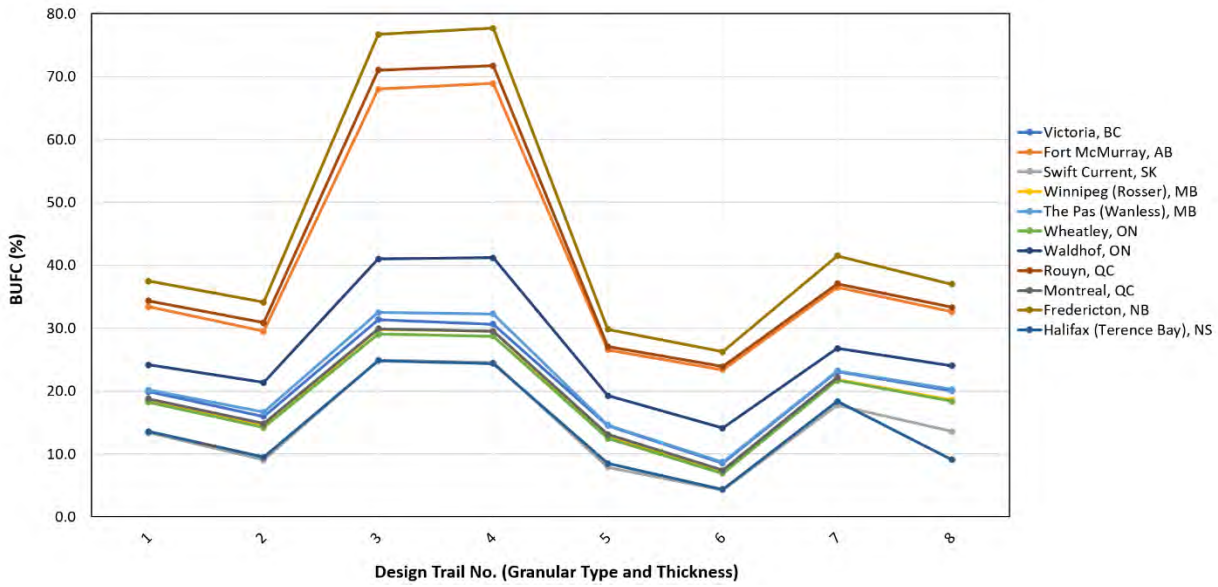



### *Impact of Granular Materials on Predicted BUFC*

The trends of PMED software predicted BUFC indicates that variations in granular base and subbase thickness and material type have a moderate influence on predicted BUFC. The trends of predicted BUFC for the design trials are presented in Figure 4. In general, increasing granular base layer thickness from 150 mm to 300 mm and improving material quality (higher stiffness) result in a reduction in BUFC, which is consistent with mechanistic expectations. For granular subbase evaluation (Trial no. 5 - 8), increasing subbase thickness from 300 mm to 600 mm leads to slight reductions in BUFC, while switching to a lower-quality subbase material result in higher BUFC. Thicker and stiffer granular layers provide better structural support, thereby reducing tensile strains at the bottom of the asphalt layer and delaying fatigue crack initiation and propagation.

These trends are consistent across most climatic regions, although the magnitude of change varies. Some of the colder regions (e.g., Rouyn and Fort McMurray) exhibit significantly higher fatigue cracking, while milder climates (e.g., Victoria, Halifax, Wheatley) show substantially lower BUFC. The influence of base properties is generally more pronounced than that of subbase properties.

Figure 4. Effects of granular materials on predicted bottom-up fatigue cracking

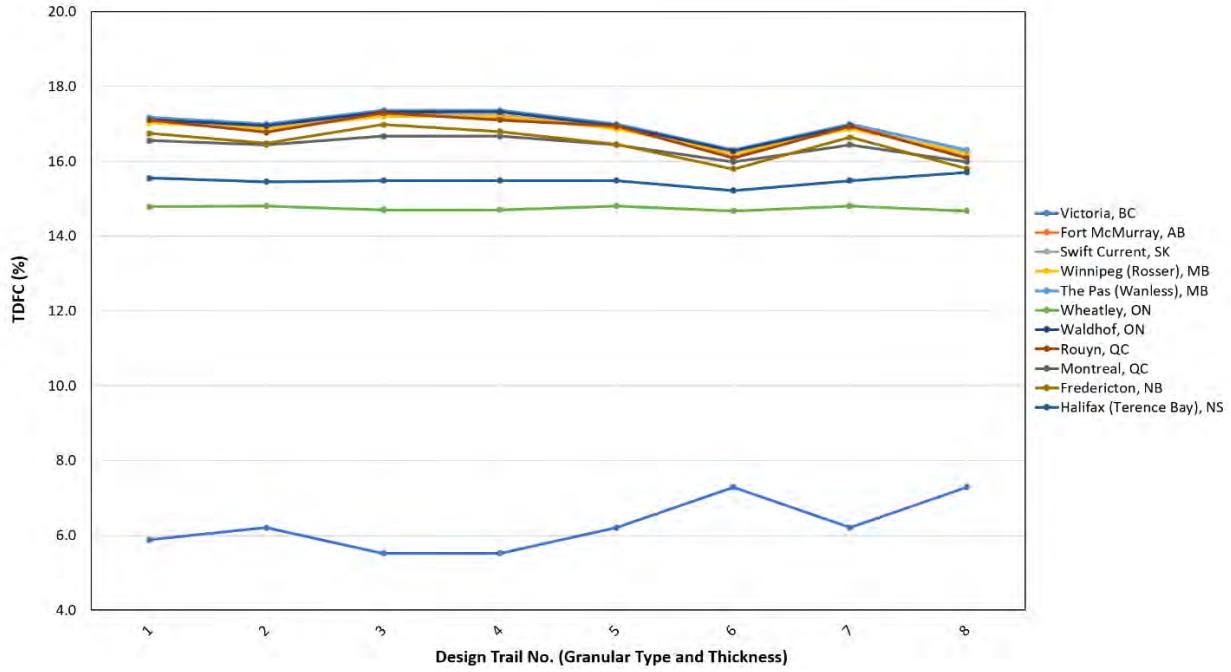



***Impact of Granular Materials on Predicted TDFC***

The trends of PMED software predicted TDFC exhibits minimal sensitivity to variations in granular base and subbase properties as compared to BUFC. The trends of predicted TDFC for the design trials are presented in Figure 5. For granular base evaluation (Trial No. 1 - 4), increasing base thickness from 150 mm to 300 mm and changing base material type from higher-quality GBC-I to lower-quality GBC-S results in no consistent change in TDFC. The predicted values remain nearly constant, with only minor fluctuations (within ~1%) that do not follow any clear trend. Similarly, for granular subbase evaluation (Trial No. 5 - 8), increasing subbase thickness from 300 mm to 600 mm and changing material type from CR-M50 to GSB-F shows minimal to no impact on TDFC. The variations observed across these trials are small and inconsistent, indicating that subbase properties have virtually no influence on predicted TDFC.

Across all climatic regions, TDFC values remain within a narrow range of approximately 16% to 17.5%, regardless of the granular configuration. This uniformity further confirms the low sensitivity of TDFC to granular material variations. The only notable exception is Victoria (BC), where TDFC values are significantly lower (approximately 5 - 7%) than other regions; however, even in this case, no consistent trend with respect to granular material changes is observed. The lack of sensitivity of TDFC to granular materials suggests that PMED may not adequately capture the interaction between surface-initiated cracking mechanisms and structural support from unbound layers.

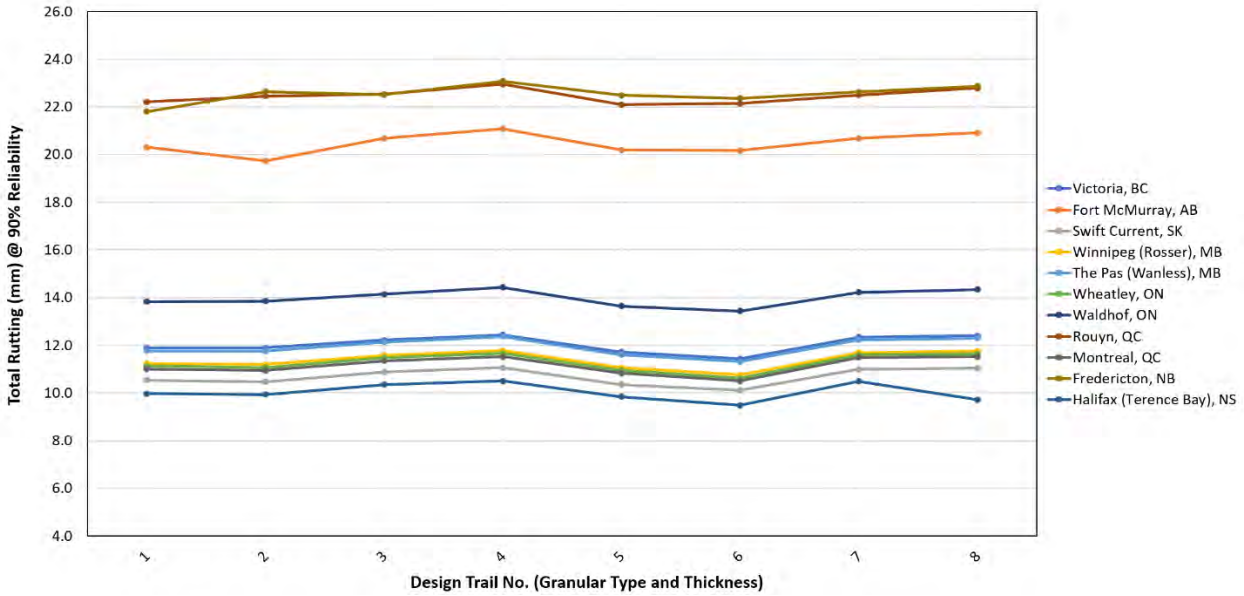
Figure 5. Effects of granular materials on predicted top-down fatigue cracking




***Impact of Granular Materials on Predicted Total Rutting***

The analysis of trial results indicates that the PMED predicted total rutting is more influenced by climatic conditions than by variations in granular base and subbase materials presented in Figure 6. The changes in base and subbase thickness and stiffness generally resulted in minor or inconsistent variations (generally less than ~1-2 mm) in total rutting across the climatic regions. Pavement sections in regions such as Fredericton (NB), Rouyn (QC), and Fort McMurray (AB) consistently exhibit higher rut depths (approximately 20 - 23 mm), whereas milder climates such as Victoria (BC), Halifax (NS), and Wheatley (ON) show lower total rutting (approximately 9 - 14 mm). This trend highlights the strong impact of environmental factors such as temperature and seasonal moisture variations on permanent deformation.

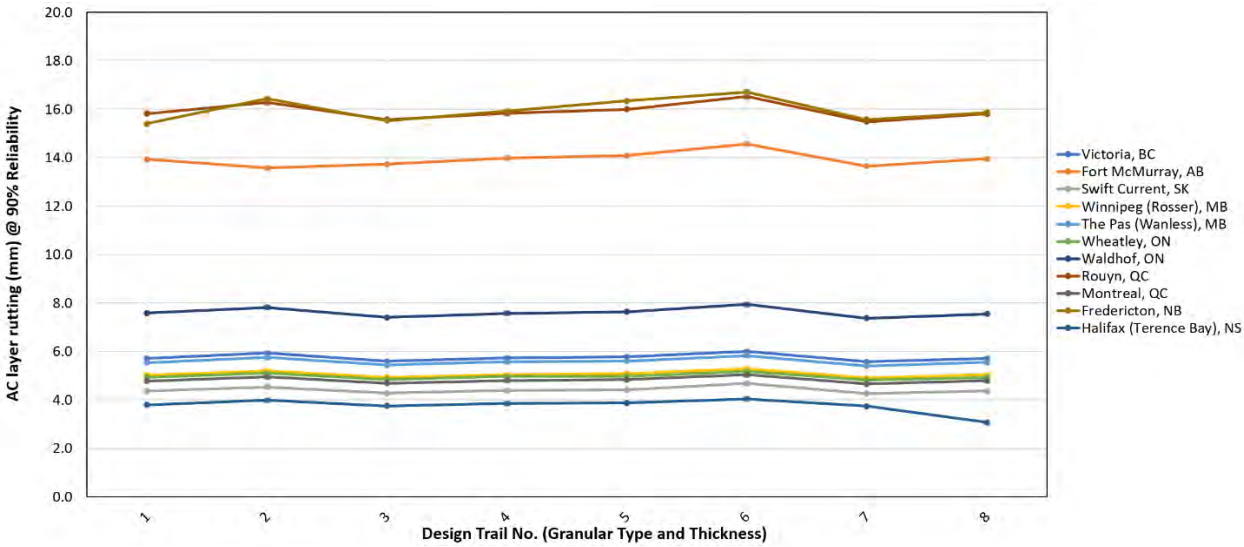
Figure 6. Effects of granular materials on predicted total rutting




***Impact of Granular Materials on Predicted Asphalt Concrete (AC) Layer Rutting***

A layer-specific rutting was also analysed in this study. The PMED predicted AC layer rutting shows very low sensitivity to changes in granular base and subbase materials across all design trials as presented in Figure 7. Increasing base or subbase thickness, as well as changing material quality, results in negligible and inconsistent changes in rutting. It is observed that the climatic conditions have a dominant influence with some regions (e.g., Fredericton, Rouyn) exhibiting higher AC rutting, while some colder or milder climates (e.g., Victoria, Halifax, Swift Current) show lower rutting.

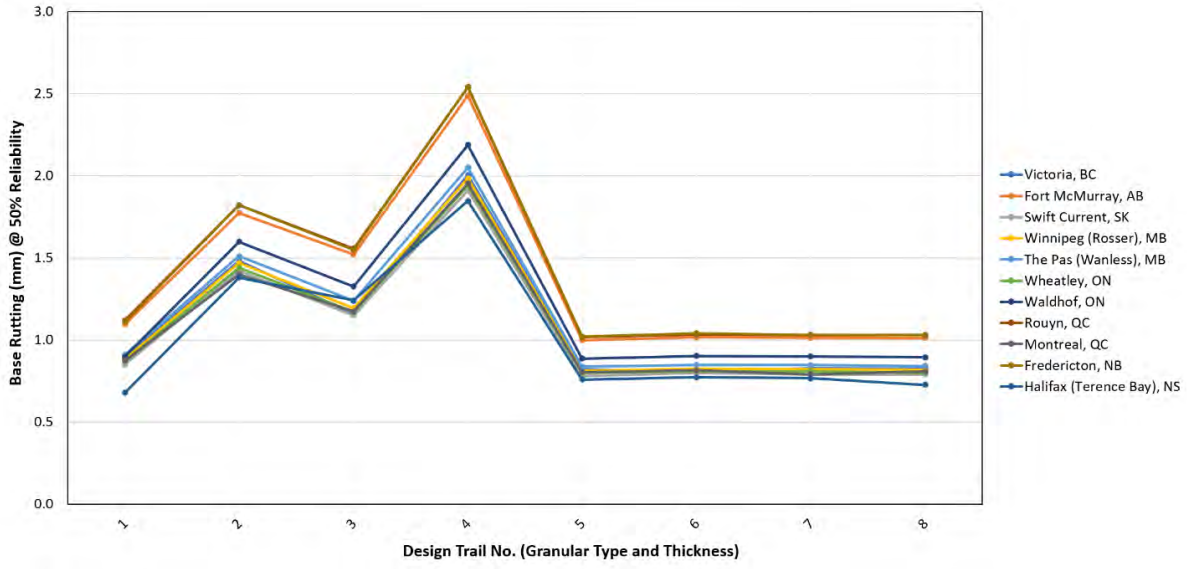
Figure 7. Effects of granular materials on predicted AC layer rutting



### *Impact of Granular Materials on Predicted Base Layer Rutting*

The PMED analysis indicates that predicted base layer rutting shows some sensitivity to variations in granular base and subbase materials; however, the trends are not fully consistent across all design trials. The trends of predicted base layer rutting for the design trials are presented in Figure 8. The model predicted that increasing the base layer thickness from 150 mm to 300 mm (Trials 1-2 and 3-4) results in a noticeable increase in base layer rutting. Similarly, changing the base material from higher-quality GBC-I to lower-quality GBC-S (Trials 1–2 vs. 3–4) also leads to higher rutting values. These trends suggest that thicker and weaker base layers tend to accumulate more deformation within the base itself, likely due to redistribution of stresses. For granular subbase evaluation (Trials 5–8), variation in subbase material thickness and type shows negligible influence on base layer rutting.

Figure 8. Effects of granular materials on predicted base layer rutting

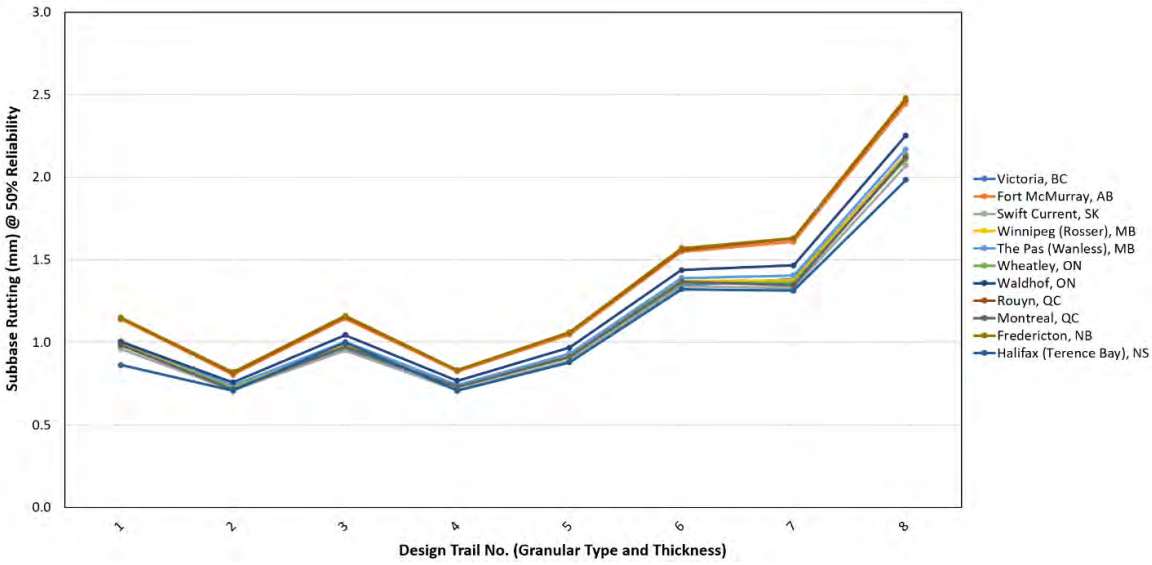



### *Impact of Granular Materials on Predicted Subbase Layer Rutting*

The trends of PMED software predicted subbase layer rutting indicate that that subbase rutting is influenced by both base and subbase properties. Thicker and stiffer base layers generally reduce subbase rutting, while thicker and weaker subbase materials result in increased subbase deformation. For example, increasing the base thickness from 150 mm to 300 mm (Trials 1-2 and 3-4) results in a reduction in subbase rutting indicating that a thicker base layer provides improved load distribution, thereby reducing stresses transmitted to the subbase layer. Similarly, the use of a higher-quality base material (GBC-I vs. GBC-S; Trials 1–2 vs. 3–4) results in slightly lower subbase rutting, reflecting the benefit of increased stiffness in the overlying layer. The trends of predicted subbase layer rutting for the design trials are presented in Figure 9.

Climatic conditions also influence subbase rutting, with colder regions such as Rouyn (QC), and Fort McMurray (AB) generally exhibiting higher rutting values, while milder climates such as Victoria (BC) and Halifax (NS) show lower deformation. However, similar to base rutting, the influence of climate is less dominant compared to the effects of material thickness and quality.

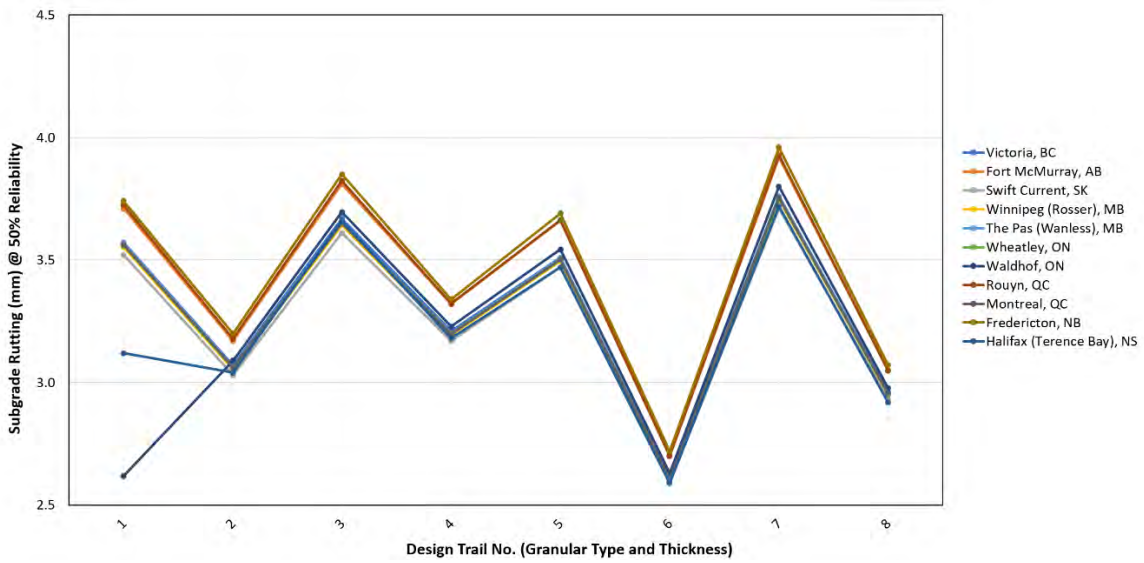
Figure 9. Effects of granular materials on predicted subbase layer rutting




***Impact of Granular Materials on Predicted Subgrade Rutting***

For subgrade layer rutting, the PMED results show that predicted subgrade deformation is influenced by both granular base and subbase properties, with generally consistent and mechanistically reasonable behaviour across the design trials as presented in Figure 10. Across all the eight design trials, subgrade rutting values vary within a relatively narrow range (approximately 2.6 mm to 4.0 mm), indicating moderate sensitivity to granular material variations. Unlike base and subbase rutting, the trends for subgrade deformation are more consistent, showing a clear reduction with increased thickness and stiffness of overlying layers. Climatic conditions also influence subgrade rutting, with some colder regions such as Rouyn (QC) and Fort McMurray (AB) generally exhibiting higher rutting values, while milder climates such as Victoria (BC) and Halifax (NS) show lower deformation levels. However, like other layer-specific rutting responses, the influence of climate is secondary to the structural effects of granular layers.

Figure 10. Effects of granular materials on predicted subgrade rutting



## Summary and Conclusions

This paper evaluated the sensitivity of PMED software predicted distresses in flexible pavements to variations in granular base and subbase materials, including differences in material properties, stiffness, and layer thickness. Eight design trials were conducted across eleven Canadian climatic regions while keeping traffic, asphalt layers, and subgrade inputs constant. The analysis focused on key performance indicators including IRI, fatigue cracking (BUFC and TDFC), total rutting, and layer-specific rutting responses. Based on the assessment and analyses of results from design trials, the following conclusions can be drawn:

- Predicted IRI shows minimal sensitivity to variations in granular material properties, whereas climatic conditions have a substantial influence on IRI.
- Predicted BUFC shows moderate sensitivity to variations in granular material properties, with thicker and stiffer granular layers generally resulting in reduced cracking, consistent with mechanistic expectations.
- Predicted TDFC exhibits negligible sensitivity to changes in granular base and subbase materials, as compared to predicted BUFC.
- Predicted total rutting is more influenced by climate than by granular material variations, with only minor and inconsistent changes observed due to thickness and stiffness. Similar trends were observed for the predicted AC layer rutting.
- A layer-specific rutting analysis indicated that the predicted base layer rutting increases with increased base thickness and lower material quality.
- Predicted subbase layer rutting is affected by both base and subbase properties. Thicker and stiffer base layers tend to reduce subbase rutting, while thicker and weaker subbase materials results in increased subbase rutting.
- Predicted subgrade rutting shows strong sensitivity to variations in granular material properties, with generally consistent and mechanistically reasonable behaviour across the design trials

These findings highlight the need for enhancement of the PMED software models for unbound-materials and further calibration and validation of their performance. Future efforts should focus on improving the representation of granular material thickness, stiffness and material properties on the prediction of permanent deformation response and cracking distresses. Future effort may also focus on establishing regional calibration parameters that better capture the empirically observed sensitivity that granular materials have regarding material quality, layer thickness and climatic conditions.

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